The Grace Programming Language
Draft Specification Version 0.3.1261

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1 Introduction

This is a specification of the Grace Programming Language. This specification is notably incomplete, and everything is subject to change. In particular, this version does *not* address:

- the library, especially collection syntax and collection literals
- nested static type system (although we've made a start)
- module system **James** ►*should write up from DYLA paper*◄
- metadata (Java's @annotations, C♯ attributes, final, abstract etc) **James** ►*should add this too*◄ **Kim** ►*Need to add syntax, but not necessarily details of which attributes are in language (yet)*◄
- immutable data and pure methods.
- reflection
- assertions, data-structure invariants, pre & post conditions, contracts **Kim** ►*Put into dialects section?*◄
- Dialects
- regexps
- libraries, including more (complex?) Numeric types and testing

For discussion and rationale, see http://gracelang.org.

Where this document gives "(options)", we outline choices in the language design that have yet to be made.

2 User Model

> *All designers in fact have user and use models consciously or subconsciously in mind as they work. Team design . . . requires explicit models and assumptions.*
>
> Frederick P. Brooks, *The Design of Design*. 2010.

1. First year university students learning programming in CS1 and CS2 classes that are based on object-oriented programming.
   (a) The courses may be structured objects first, or imperative first. Is it necessary to support "procedures first"?
   (b) The courses may be taught using dynamic types, static types, or both in combination (in either order).
   (c) We aim to offer some (but not necessarily complete) support for "functional first" curricula, primarily for courses that proceed rapidly to imperative and object-oriented programming.
2. University students taking second year classes in programming; algorithms and data structures, concurrent programming, software craft, and software design.
3. Faculty and teaching assistants developing libraries, frameworks, examples, problems and solutions, for first and second year programming classes.
4. Programming language researchers needing a contemporary object-oriented programming language as a research vehicle.
5. Designers of other programming or scripting languages in search of a good example of contemporary OO language design.

3 Syntax

> *Much of the following text assumes the reader has a minimal grasp of computer terminology and a "feeling" for the structure of a program.*
>
> Kathleen Jensen and Niklaus Wirth, *Pascal: User Manual and Report.*

Grace programs are written in Unicode. Reserved words are written in the ASCII subset of Unicode. As a matter of policy, the names of methods defined in the required libraries are also restricted to the ASCII subset of Unicode. James ▶*and the character π*◀

3.1 Layout

Grace uses curly brackets for grouping, and semicolons as statement terminators, and infers semicolons at the end of lines. Code layout cannot be inconsistent with grouping.

code with punctuation:

```
while {stream.hasNext} do {
    print(stream.read);
};
```

code without punctuation:

```
while {stream.hasNext} do {
    print(stream.read)
}
```

A line break followed by an increase in the indent level implies a line continuation, whereas line break followed by the next line at the same or lesser indentation implies a semicolon (if one is permitted syntactically).

James ▶*We need to define this precisely*◀

3.2 Comments

Grace's comments start with a pair of slashes // and are terminated by the end of the line, as in C++ and Java. However, comments are *not* treated as white-space. Each comment is conceptually attached to the smallest immediately preceding syntactic unit, except that comments following a blank line are attached to the largest immediately following syntactic unit.

```
// comment, to end of line
```

3.3 Identifiers

Identifiers must begin with a letter, which is followed by a sequence of zero or more letters, digits and ' characters.

An underscore "_" acts as a placeholder identifier: it is treated as a fresh identifier everywhere it is used.

3.4 Reserved Words and Reserved Operators

Grace has the following reserved words and reserved operators. The ? indicates words related to design options not yet chosen.

class def inherits is method object
outer prefix return self Selftype(?) **super type var where**

. := = ; { } [ ] " ( ) : –>

James ▶*we should decide how to handle these properly, esp names always defined in the standard library: true, false, etc*◀

3.5 Tabs and Control Characters

Newline can be represented by the unicode newline character, by carriage return, or by line feed; a line feed that immediately follows a carriage return is ignored.

Tabs and all other non-printing control characters (except carriage return,line feed, and line separator) are syntax errors, even in a string literal. (There are escape sequences for including special characters in string literals.)

4 Built-in Objects

4.1 Numbers

Grace supports a single type Number. Number supports at least 64-bit precision floats. Implementations may support other numeric types: a full specification of numeric types is yet to be completed.

Grace has three syntactic forms for numerals (that is, literals that denote Numbers).

1. Decimal numerals, written as strings of digits, optionally preceded by a minus.

2. Explicit radix numerals, written as a (decimal) number between 2 and 35 representing the radix, a leading x, and a string of digits, where the digits from 10 to 35 are represented by the letters A to Z, in either upper or lower case. As a special case, a radix of 0 is taken to mean a radix of 16. Explicit radix numerals may optionally be preceded by a minus.

3. Base-exponent numerals, always in decimal, which use e as the exponent indicator. Base-exponent numerals may optionally be preceded by a minus.

All literals evaluate to exact rational numbers; explicit conversions (such as f64) must be used to convert rationals to other objects.

Examples

```
1
−1
42
3.14159265
13.343e−12
−414.45e3
16xF00F00
2x10110100
0xdeadbeef // Radix zero treated as 16
```

4.2 Booleans

The predefined constants true and false denote the only two values of Grace's Boolean type. Boolean operators are written using && for and, || for or, and prefix ! for not.

Examples

```
P && Q
toBe || toBe.not
```

"Short circuit" (a.k.a non-commutative) boolean operators take blocks as their second argument:

Examples

```
P.andAlso { Q }
toBe.orElse { ! toBe }
```

4.3 Strings and Characters

String literals in Grace are written between double quotes. Strings literals support a range of escape characters such as `"\t\b"`, and also escapes for Unicode; these are listed in Table 1 Individual characters are represented by Strings of length 1. Strings are immutable Grace values (see §10) and so may be interned. Strings conform to the protocol of an immutable IndexableCollection, and Grace's standard library includes mechanisms to support efficient incremental string construction.

Escape	Meaning	Escape	Meaning
\\	backslash	\'	single quote
\"	double quote	\b	backspace
\n	line-feed	\r	carriage-return
\t	tab	\l	unicode NEL
\f	page down	\e	escape
\{	left brace	\}	right brace
\ (\ space)	non-breaking space		

Table 1: Grace string escapes.

Examples

```
"Hello World!"
"\t"
"The End of the Line\n"
"A"
```

4.3.1 String interpolation

Within a string literal, expressions enclosed in braces are treated specially. The expression is evaluated, the asString method is requested on the resulting object, and the resulting string is inserted into the string literal in place of the brace expression.

Examples

```
"Adding {a} to {b} gives {a+b}"
```

«Guillemets» may be used for strings that don't support the interpolation feature.

5 Blocks

Grace blocks are lambda expressions; they may or may not have parameters. If a parameter list is present, the parameters are separated by commas and the list is terminated by the −> symbol.

```
{do.something}
{ i −> i + 1}
{ sum, next −> sum + next }
```

Blocks construct objects containing a method named apply, apply(n), apply(n, m), ... depending on the number of parameters. Requesting the apply method evaluates the block. It is an error to provide the wrong number of arguments.

```
for (1..10) do {
    i −> print i
}
```

might be implemented as

```
method for (collection) do (block) {
        ...
        block.apply(collection.at(i))
        ...
}
```

Here is another example:

```
var sum := 0
def summingBlock : Block<Number,Number> =
    { i:Number −> sum := sum + i }
summingBlock.apply(4)  // sum now 4
summingBlock.apply(32)  // sum now 36
```

Blocks are lexically scoped inside their containing method or block. A "naked" block literal, that is, a block literal that is neither the target of a method request nor an argument, is a syntax error.

The body of a block consists of a sequence of declarations and expressions.

6 Declarations

Declarations of constants and variables may occur anywhere within an object, a method, or a block: their scope is the whole of their defining object, method, or block. Grace has a single namespace for all identifiers; this shared namespace is used for methods, constants, variables and types. It is an error to declare a constant or variable that shadows a lexically-enclosing constant or variable.

6.1 Constants

Constant definitions are introduced using the **def** keyword; they bind an identifier to the value of an initialising expression, optionally at a precise type. Constants cannot be re-bound.

Examples

```
def x = 3 * 100 * 0.01
def x:Number = 3  // means the same as the above
def x:Number      // Syntax Error: x must be initialised
```

6.2 Variables

Variable definitions are introduced using the **var** keyword; they optionally bind an identifier to the value of an initialising expression, optionally at a precise type. Variables can be re-bound to new values as often as desired, using an assignment statement. If a variable is declared without an initializing expression, it is said to be *uninitialized*; any attempt to access the value of an initialized variable is an error. This error may be caught either at run time or at compile time, depending on the cleverness of your implementor.

Examples

```
var x:Rational := 3 // explicit type
var x:Rational // ok; x must be initialized before being referenced
var x := 3 // x has type dynamic
var x // x is uninitialised and dynamic
```

6.3 Fields

Constants and variables declared directly inside an object constructor represent *fields* of that object. A field declaration of x can be annotated to

create a reader method x and, if x is a variable, a writer method x:=(_), as described in Section 8.8.1. Because these methods are (deliberately) syntactically identical to direct references to x, x becomes inaccessible except through use of the methods. You can think of the real field as having a unique secret name, which is known only to the reader and writer methods.

In contrast, block and method temporary variables really exist, and can be the targets of real assignment statements.

Assignment statements return the value done of type Done.

James ►*I don't like this description field access*◄

6.4 Methods

Methods are declared with the **method** keyword, a name, optionally a parameter list, potentially repeated, optionally a return type declaration, and a method body. Methods may not be nested.

Methods may contain one or more **return** e statements. If a **return** statement is executed, the method terminates with the value of the expression e. If the method returns Done, then no expression may follow the **return**. If execution reaches the end of the method body without executing a **return**, the method terminates and returns the value of the last expression evaluated.

Methods can be named by an identifier suffixed with ":="; this form of name is conventionally used for writer methods, both user-written both automatically generated and custom, as exemplified by the example value below.

Prefix operator methods are named "**prefix**" followed by the operator character(s).

Methods may have "repeated parameters" to allow them to take a variable number of parameters, that is, to provide method of "variable arity" (called "varargs" in some other languages). A repeated parameters, if present, must be the last parameter in any on the parameter lists following a part of a multipart method name. Repeated parameters are designated by a star "∗" before the name of the parameter. Inside the method, a repeated parameter has the type of an immutable collection of the declared type — for example, a parameter declared ∗args : String has the type args : ImmutableCollection<String>

Methods may be declared with generic type parameters, in which case they must be requested with generic type arguments. **Andrew** ►*Why do we call them "generic" type parameters and "generic" type arguments? Why not just "type parameters" and "type arguments"?*◄ **Andrew** ►*This contradicts §8.9, which says that the type arguments are optional.*◄ Generic type parameters may be constrained with **where** clauses.

Examples

```
method pi {3.141592634}

method greetUser {print ''Hello World!''}

method +(other : Point) −> Point { (x +other.x) @ (y +other.y) }

method + (other)
        { (x +other.x) @ (y +other.y) }

method + (other)
        { return (x +other.x) @ (y +other.y) }

method value:=(n : Number) −> Done {
        print "value currently {value}, now assigned {n}"
        super.value:= n }

method either (a : Block0<Done>) or (b : Block0<Done>) −> Done {
    if (random.nextBoolean)
        then {a.apply} else {b.apply} }

method print( ∗args : Printable ) −> Done

method sumSq<T>(a : T, b : T) −> T where T <: Numeric
        {(a ∗ a) + (b ∗ b)}

method prefix− −> Number
        { 0 − self }
```

Andrew ▶*The where T<:Numeric should be T matches Numeric*◀

7 Objects and Classes

Grace **object** constructor expressions and declarations produce individual objects. Grace provides **class** declarations to create classes of objects all of which have the same structure.

Grace's class and inheritance design is complete but tentative. We need experience before confirming the design.

7.1 Objects

Objects are created by object literals. The body of an object literal consists of a sequence of declarations.

```
object {
    def colour:Colour = Colour.tabby
    def name:String = "Unnamed"
    var miceEaten := 0
    method eatMouse {miceEaten := miceEaten + 1}
}
```

Object literals are lexically scoped inside their containing method, or block. In particular, any object-level expressions, initializer expressions and method bodies are executed in that lexical context. Each time an object literal is executed, a new object is created.

Object literals are expressions that evaluate to an object with the given features. Object literals can also contain statements, which are executed as a side-effect of evaluating the object literal. Thus, constant can be defined by an object literal, like this:

```
def unnamedCat = object {
    def colour : Colour = Colour.tabby
    def name : String = "Unnamed"
    var miceEaten := 0
    method eatMouse {miceEaten := miceEaten + 1 }
    print "The Cat {name} has been created."
}
```

to bind a name to an object. Repeated invocations of the reader method unnamedCat return the same object.

Andrew ►*Do all of the names declared in a scope come into existence simultaneously when that scope is first entered?*◄ **James** ►*That's the aim. Minigrace does not do that.*◄

7.2 Classes

Class declarations combine the definition of a factory object with the definition of a single object creation method on that object. This method creates "instances of the class". A class declaration is syntactically a combination of an object literal and a method declaration; everything in the body of the class declaration can be imagined as being part of an implicit object literal that is executed each time an "instance of the class" is created.

Examples

```
class aCat.ofColour ( c:Colour ) named (n: String) {
    def colour:Colour = c
    def name:String = n
    var miceEaten := 0
    method eatMouse {miceEaten := miceEaten + 1}
    print "The Cat {name} has been created."
}
```

This declares a class, binds it to the name aCat, and declares an instance creation method on that class called ofColour()named(). This method takes two arguments, and returns a newly-created object with the fields and methods listed. Creating the object also has the side-effect of printing the given string, since executable code in the class declaration is also part of the implicit object literal.

This class might be used as follows:

```
def fergus = aCat.ofColour(Colour.Tortoiseshell)named "Fergus"
```

This creates an object with fields colour (set to Colour.Tortoiseshell), name (set to "Fergus"), and miceEaten (initialized to 0), prints "The Cat Fergus has been created", and binds fergus to this object.

The above declaration for aCat is equivalent to the following nested object declarations:

James ►*Where does the name "CatFactory" come from? Is this really, **really** what we want? If so, we need to say so!*◄

```
def aCat = object { // a cat factory
    method ofColour (c: Colour) named (n: String)
        object { // the cat herself
            def colour:Colour = c
            def name:String = n
            var miceEaten := 0
            method eatMouse {miceEaten := miceEaten + 1}
            print "The Cat {name} has been created."
        }
    }
}
```

If the programmer wants a factory object with more than one method, she is free to build such an object using nested object constructors.

Kim ▶*We also need to discuss whether the CatFactory there really is equivalent to the CatFactory on the previous page. (As you might expect, the problem is extending it – especially if there were protected methods)*◀

7.3 Inheritance

Grace class declarations supports inheritance with "single subclassing, multiple subtyping" (like Java), by way of an **inherits** C clause in a class declaration or object literal.

A new declaration of a method can override an existing declaration, but overriding declarations must be annotated with **is** override. Overridden methods can be accessed via **super** calls (see §8.6). It is a static error for a field to override another field or a method. This example shows how a subclass can override accessor methods for a variable defined in a superclass (in this case, to always return 0 and to ignore assignments).

Andrew ▶*I would like the <override> annotation to come after the name of the method, not before the* ***method*** *keyword.*◀ James ▶*We need a coherent story about annotations.*◀

```
class aPedigreeCat.ofColour (aColour) named (aName) {
    inherits aCat.ofColour (aColour) named (aName)
    var prizes := 0
    method miceEaten is override {0}
    method miceEaten:= (n:Number) is override {return}
                                        // ignore attempts to change it
}
```

The right hand side of an **inherits** clause is restricted to be an expression that creates a new object, such as the name of a class followed by a request on its constructor method, or a request to copy an exiting object.

James ▶*need to talk about inherits on object declarations*◀

When executing inherited code, self is bound to the object under construction, self requests are resolved in the same way as the finally constructed object, def and var initialisers and inline code are run in order from the topmost superclass down to the bottom subclass. Accesses to unitialised vars and defs raise uninitialised exceptions (§6.2).

7.4 Understanding Inheritance (under discussion)

Grace's class declarations can be understood in terms of a flattening translation to object constructor expressions that build the factory object. Under-

standing this translation lets expert programmers build more flexible factories.

The above declaration for **class** aPedigreeCat is broadly equivalent to the following nested object declarations, not considering types, modules, and *renaming superclass methods so that an object's method names must actually be unique.*

```
def aPedigreeCat = object { // a cat factory
    method ofColour (c: Colour) named (n: String) -> PedigreeCat {
        object { // the cat herself
            def colour : Colour := c
            def name : String := n
            var Cat__miceEaten := 0 // ugly. very ugly
            var prizes = 0
            method miceEaten {0}
            method miceEaten:=(n:Number) {return} // ignore attempts to change it
        } // object
    } // method
} // object
```

Andrew ▶*This translation is confusing, because it re-writes both the class syntax and the inheritance syntax. I suggest that we do these one at a time, in the appropriate places.*◀

7.5 Generic Classes

Classes may optionally be declared with generic type parameters. The corresponding requests on the factory methods must be provided with type arguments. Generic type parameters may be constrained with **where** clauses.

Examples

```
class aVector.ofSize(size)<T> {
    var contents := Array.size(size)
    method at(index : Number) -> T {return contents.at() }
    method at(index : Number) put(elem : T) { }
}

class aSortedVector.ofSize<T>
    where T <: Comparable<T> {
        ...
```

```
}
```

Andrew ▶*That last <: needs to be a matches, I think*◀

8 Method Requests

Grace is a pure object-oriented language. Everything in the language is an object, and all computation proceeds by *requesting* an object to execute a method with a particular *name*. The response of the object is to execute the method. We distinguish the act of *requesting* a method (what Smalltalk calls "sending a message"), and *executing* that method. Requesting a method involves only the object receiving the request, the method name, and possibly some arguments. In contrasty, executing the method involves the code of the method, which is local to the receiver.

8.1 Named Requests

A named method request is a receiver followed by a dot ".", then a method name (an identifier), then any arguments in parentheses. Parentheses are not used if there are no arguments. To improve readability, a the name of a method that takes more than one parameter may comprise multiple parts or "words", with argument lists between the words, and following the last word. For example

```
method drawLineFrom(source)to(destination) { ... }
```

The name of a method and the position of its argument lists within that name is determined when the method is declared. When reading a request of a multi-part method name, you should continue accumulating words and argument lists as far to the right as possible right as possible.

If the receiver of a named method is **self** it may be left implicit, *i.e.*, the **self** and the dot may both be omitted.

Grace does not allow the "overloading" of method names: the type and number of arguments in a method request does not influence the name of the method that is being requested.

Parenthesis may be omitted where they would enclose a single argument that is a string or block literal.

Examples

```
canvas.drawLineFromPoint(p1)toPoint(p1)
canvas.drawLineFromPoint(origin)ofLenthXY(3,5)
canvas.movePenToXY(x,y)
```

```
canvas.movePenToPoint(p)
print "Hello world"
size
```

8.2 Assignment Requests

An assignment request is a variable followed by ":=", or it is a request of a method whose name ends with :=, in each case followed by a single argument. Spaces are optional before and after the ":=".

Examples

```
x := 3
y:=2
widget.active := true
```

Assignment methods return Done.

8.3 Binary Operator Requests

Binary methods have a receiver and one argument. Grace allows operator symbols to name binary methods, but the receiver of a binary method must always be explicit.

A binary operator method is named by one or more operator characters, provided that the operator is not a reserved symbol of the Grace language. So, for example, +, ++ and .. are valid operator symbols, but . is not, because it is reserved. **Andrew** ▶*This rules out = as an operator. Do we want to reconsider?*◀

Most Grace operators have the same precedence: it is a syntax error for two different operator symbols to appear in an expression without parenthesis to indicate order of evaluation. The same operator symbol can be requested more than once without parenthesis; such expressions are evaluated left-to-right.

Four simple arithmetic operators do have precedence: / and ∗ over + and −. **James** ▶*James and Andrew hate this exception with a vengeance, but understand why it is here.*◀ **Andrew** ▶*Do * and + have higher or lower precedence that the other operators?*◀

Examples

```
1 + 2 + 3       // evaluates to 6
1 + (2 * 3)     // evaluates to 7
```

```
(1 + 2) * 3     // evaluates to 9
1 + 2 * 3       // evaluates to 7
1 +*+ 4 -*- 4   // syntax error
```

Named method requests without arguments bind more tightly than operator method requests. The following examples show the Grace expressions on the left, and the parse on the right.

Examples

`1 + 2.i`	`1 + (2.i)`
`(a * a) + (b * b).sqrt`	`(a * a) + ((b *b).sqrt)`
`((a * a) + (b * b)).sqrt`	`((a * a) + (b *b)).sqrt`
`a * a + b * b`	`(a * a) + (b *b)`
`a + b + c`	`(a + b) + c`
`a - b - c`	`(a - b) - c`

8.4 Unary Prefix Operator Requests

Grace supports unary methods named by operator symbols that precede the explicit receiver. (Since binary operator methods must also have an explicit receiver, there is no syntactic ambiguity.)

Prefix operators bind less tightly than other method requests, and therefore need parenthesis to disambiguate. **Andrew** ►*This seems backwards — in math prefix operators bind* more *tightly. The statement above is also a non sequitur.*◄

Examples

```
-3 + 4
(-b).squared
-(b.squared)
- b.squared // parses as -(b.squared)

status.ok := !engine.isOnFire && wings.areAttached && isOnCourse
```

Andrew ►*By the above rule, we are OK only if the wings have fallen off and we are off-course!*◄

8.5 Accessing Operator Requests

Grace supports operators [...] and [...]:=, which can be defined in libraries, *e.g.*, for indexing and modifying collections.

Examples

```
print( a[3] ) // requests method [] on a with argument 3
a[3] := "Hello" // requests method []:= on a with arguments 3 and "Hello"
```

Note: Somewhere we need to have a list of reserved operators that cannot be used normally. **Andrew** ►*eh? What does that mean?*◄

8.6 Super Requests

The reserved word **super** may be used only as an explicit receiver. In overriding methods, method requests with the pseudo-receiver **super** request the prior overridden method with the given name from **self**. Note that no "search" is involved; super-requests can be resolved statically, unlike other method requests.

Examples

```
super.value
super.bar(1,2,6)
super.doThis(3) timesTo("foo")
super + 1
!super

foo(super) // syntax error
1 + super // syntax error
```

8.7 Outer Requests

The reserved word **outer** denotes the object enclosing **self**; it is an error if there is no such enclosing object. Moreover, **outer**.**outer** denotes the object enclosing **outer**, and so on, for as many **outer**s as there are enclosing objects.

Andrew ►minigrace *recognizes* ***outer*** *as a* method *that can be requested of any object and that answers a reference to its enclosing object. Do we want to support this?*◄

Examples

```
outer
outer.value
outer.bar(1,2,6)
outer.outer.doThis(3) timesTo("foo")
outer + 1
```

```
!outer
```

8.8 Encapsulation

Grace has different default encapsulation rules for methods and fields. The defaults can be changed by explicit annotations. The details are as follows.

8.8.1 Methods

By default, methods are public, which means that they can be requested by any client that has access to the object. Thus, any expression can be the target of a request for a public method.

If a method is annotated **is** confidential, it can be requested only on the target **self** or **super**. This means that such a method is accessible to the object that contains it, and to inheriting objects, but not to client objects. **Andrew** ►*Here, "target" means the syntactic thing to the left of the dot, while "receiver" means the dynamic thing that gets the request. I'm not sure if these are the right names.*◄

Methods can be explicitly annotated as **is** public; this has no effect unless a dialect changes the default encapsulation. **Andrew** ►*If this is possible!*◄

Grace does not have private methods. Thus, all methods can be overridden.

8.8.2 Fields

Variables and definitions (**var** and **def** declarations) immediately inside an object constructor create *fields* in that object. These fields behave like other variables and definitions, but also behave like methods, in that requests on the object can be used to access them.

A field declared as **var** x can be read using the request x and assigned to using the assignment request x:=() (see §8.2). A field declared as **def** y can be read using the request y, and cannot be assigned. By default, fields are *confidential*: they can be accessed and assigned from the object itself, and from inheriting objects, but not from clients. **Andrew** ►*What about from inner objects? Can I say* ***outer****.confidentialField.*◄ In other words, these requests can be made only on **self** and **super** **Andrew** ►*and* ***outer****?*◄ . However, fields can be made available to client objects using annotations.

The annotation readable can be applied to a **def** or **var** declaration, and makes the accessor request available to any object. The annotation writable can be applied to a **var** declaration, and makes the assignment request available to any object. It is also possible to annotate a field declaration as

public. In the case of a **def**, public is equivalent to readable. **Andrew** ▶*Do we want this? It's an "option"*◀ In the case of a **var**, public is equivalent to readable, writable.

Fields and methods share the same namespace. The syntax for variable access is identical to that for requesting a reader method, while the syntax for variable assignment is identical to that for requesting an assignment method. This means that an object cannot have a field and a method with the same name, and cannot have an assignment method x:=() as well as a **var** field x.

Examples

```
object {
    def a = 1                    // Confidential access to a
    def b is public = 2          // Public access to b
    def c is readable = 2        // Public access to c
    var d := 3                   // Confidential access and assignment
    var e is readable            // Public access and confidential assignment
    var f is writable            // Confidential access, public assignment
    var g is public              // Public access and assignment
    var h is readable, writable  // Public access and assignment
}
```

8.9 Private Fields

Grace does not have private fields; all fields can be accessed from subobjects. However, the parameters and temporary variables of constructor methods can be used to obtain an effect similar to privacy

Examples

```
method newShipStartingAt(s:Vector2D)endingAt(e:Vector2D) {
    // returns a battleship object extending from s to e. This object cannot
    // be asked its size, or its location, or how much floatation remains.
    assert ( (s.x == e.x) || (s.y == e.y) )
    def size = s.distanceTo(e)
    var floatation := size
    object {
        method isHitAt(shot:Vector2D) {
            if (shot.onLineFrom(s)to(e)) then {
                floatation := floatation −1
                if (floatation == 0) then { self.sink }
```

```
                    true
                } else { false }

            }
            ...
        }
    }
```

8.10 Generic Method Requests

Methods that have type parameters may optionally be requested with explicit type arguments. When a method declared with type parameters is requested in a statically typed context without explicit type arguments, the type arguments are inferred. **Andrew** ►*We haven't defined "statically typed context". More recent thinking is that types are always inferred if not given explicitly (the inferred types may be Dynamic).*◄

Examples

```
sumSq<Integer64>(10.i64, 20.i64)

sumSq(10.i64, 20.i64)
```

Andrew ►*An example that gives the method definition, and uses the type in some way, would be more useful*◄

8.11 Precedence of Method Requests

Grace programs are formally defined by the language's grammar (see appendix B). The grammar gives the following precedence levels; higher numbers bind more tightly.

1. Assignment operator := as a suffix to a named request or accessing operator.

2. "Other" operators; no priority for different operators; associate left to right.

3. "Additive" operators + and −; associate left to right.

4. "Multiplicative" operators ∗ and /; associate left to right.

5. Prefix operators; associate right to left.

6. Named requests (with or without arguments); the accessing operator. Multi-part named requests accumulate words and arguments as far to the right as possible.

7. Literals (numbers, strings, objects, types, ...); parenthesized expressions.

9 Control Flow

Control flow statements in Grace are syntactically method requests. This allows instructors to use libraries to define domain-specific control flow constructs that look the same as the rest of Grace.

9.1 Basic Control Flow

If statements:

```
if (test) then {block}

if (test) then {block} else {block}
```

While statement:

```
while {test} do {block}
```

For statement:

```
for (collection) do {item −> block body}

for (course.students) do { s:Student −> print s }

for (0..n) do { i −> print i }
```

To allow for conventional syntax with a leading keyword (if, while, for, etc.), these methods are treated as if they are sent to **outer**. Methods defined in a dialect are treated as if they are defined on an outer-level enclosing object. **Andrew** ►*Add Xref to as-yet- unwritten section on dialects*◄

9.2 Case

The match–case construct which attempts to match its first argument against a series of patterns introduced by case. Patterns support destructuring.

Andrew ▶*The description of blocks in §5 needs to be enhanced to talk about blocks like the 1st and 3rd examples below.*◀

Examples

```
match (x)
    case { 0 -> "Zero" }
    // match against a literal constant
    case { s:String -> print(s) }
    // typematch, binding s − identical to block with typed parameter
    case { (pi) -> print("Pi = " ++ pi) }
    // match against the value of an expression − requires parenthesis
    case { _ : Some(v) -> print(v) }
    // typematch, binding a variable − looks like a block with parameter
    case { _ -> print("did not match") }
    // match against placeholder, matches anything
```

The case arguments are patterns: objects that understand the request match( ) and return a MatchResult, which is either a SuccessfulMatch object or a FailedMatch object. Each of the case patterns is requested to match(x) in turn, until one of them returns SuccessfulMatch(v); the result of the whole match–case construct is v.

9.2.1 Patterns

Pattern matching is based around the Pattern objects, which are objects that respond to a request match(anObject). The pattern tests whether or not the argument to match "matches" the pattern, and returns a MatchResult, which is either a SuccessfulMatch or a FailedMatch. An object that has type SuccessfulMatch behaves like the boolean true but also responds to the requests result and bindings. An object that has type FailedlMatch behaves like the boolean false but also responds to the requests result and bindings.

Andrew ▶*This needs to be completed. I started, using the information in the DLS paper, but soon got confused. The tone, if not the content, of much of what follows is not appropriate for the spec.*◀

result is the return value, typically the object matched, and the bindings are a list of objects that may be bound to intermediate variables, generally used for destructuring objects.

For example, in the scope of this Point type:

```
type Point = {
  x -> Number
```

```
  y -> Number
  extract -> List<Number>
}
```

implemented by this class:

```
class aCartesianPoint.x(x':Number)y(y':Number) -> Point {
  method x { x' }
  method y { y' }
  method extract { aList.with(x, y) }
}
```

these hold:

```
def cp = aCartesianPoint.new(10,20)

Point.match(cp).result          // returns cp
Point.match(cp).bindings        // returns an empty list
Point.match(true)               // returns FailedMatch
```

9.2.2 Matching Blocks

Blocks with a single parameter are also patterns: they match any object that can validly be bound to that parameter. For example, if the parameter is annotated with a type, the block will successfully match an object that has that type, and will fail to match other objects.

Matching-blocks support an extended syntax for their parameters. In addition to being a fresh variable, as in a normal block, the parameter may also be a pattern. Matching-blocks are themselves patterns: one-argument **Andrew** ►*Here I gave up!*◄ (matching) block with parameter type A and return type R also implements Pattern<R,Done>.

A recursive, syntax-directed translation maps matching-blocks into blocks with separate explict patterns non-matching blocks that are called via apply only when their patterns match.

First, the matching block is flattened — translated into a straightforward non-matching block with one parameter for every bound name or placeholder. For example:

```
{ _ : Pair(a,Pair(b,c)) -> "{a} {b} {c}" }
```

is flattened into

```
{ _, a, b, c -> "{a} {b} {c}" }
```

then the pattern itself is translated into a composite object structure:

```
def mypat =
  MatchAndDestructuringPattern.new(Pair,
     VariablePattern.new("a"),
     MatchAndDestructuringPattern.new(Pair,
        VariablePattern.new("b"), VariablePattern.new("c")))
```

Finally, the translated pattern and block are glued together via a LambdaPattern:

```
LambdaPattern.new( mypat, { _, a, b, c -> "{a} {b} {c}" } )
```

The translation is as follows:

e	[[e]]
_ : e	[[e]]
_	WildcardPattern
v (fresh, unbound variable)	VariablePattern("v")
v (bound variable)	error
v : e	AndPattern.new(VariablePattern.new("v"),[[e]])
e(f,g)	MatchAndDestructuringPattern.new(e, [[f]], [[g]])
literal	literal
e not otherwise translated	e

9.2.3 Implementing Match-case

Finally the match(1)*case(N) methods can be implemented directly, e.g.:

```
method match(o : Any)
          case(b1 : Block<B1,R>)
          case(b2 : Block<B2,R>)
  {
    for [b1, b2] do { b ->
      def rv = b.match(o)
      if (rv.succeeded) then {return rv.result}
    }

    FailedMatchException.raise
  }
```

or (because matching-blocks are patterns) in terms of pattern combinators:

```
method match(o : Any)
        case(b1 : Block<B1,R>)
        case(b2 : Block<B2,R>)
  {
    def rv = (b1 || b2).match(o)
    if (rv.succeeded) then {return rv.result}

    FailedMatchException.raise
  }
```

First Class Patterns While all types are patterns, not all patterns are types. For example, it would seems sensible for regular expressions to be patterns, potentially created via one (or more) shorthand syntaxes (shorthands all defined in standard Grace)

```
match (myString)
  case { "" −> print "null string" }
  case { Regexp.new("[a−z]∗") −> print "lower case" }
  case { "[A−Z]∗".r −> print "UPPER CASE" }
  case { /"[0−9]∗" −> print "numeric" }
  case { ("Forename:([A−Za−z]∗)Surname:([A−Za−z]∗)".r2)(fn,sn) −>
              print "Passenger {fn.first} {sn}"}
```

With potentially justifiable special cases, more literals, e.g. things like tuples/lists could be descructured `[a,b,...] −>a ∗ b`. Although it would be very nice, it's hard to see how e.g. points created with `"3@4"` could be destructed like `a@b −>print "x: {a}, y: {b}"` without yet more bloated special-case syntax.

Discussion This rules try to avoid literal conversions and ambiguous syntax. The potential ambiguity is whether to treat something as a variable declaration, and when as a first-class pattern. These rules (should!) treat only fresh variables as intended binding instances, so a "pattern" that syntactically matches a simple variable declaration (as in this block `{ empty −>print "the singleton empty collecti` will raise an error — even though this is unambiguous given Grace's no shadowing rule.

Match statements that do nothing but match on types must distinguish **Andrew** ►*something?*◄ syntactically from a variable declaration, *e.g.*:

```
match (rv)
  case { (FailedMatch) −> print "failed" }
```

```
    case { _ : SuccessfulMatch −> print "succeeded" }
```

while writing just:

```
match (rv)
  case { FailedMatch −> print "failed" }
  case { SuccessfulMatch −> print "succeeded" }
```

although closer to the type declaration, less gratuitous, and perhaps less error-prone, would result in two errors about variable shadowing.

Self-Matching For this to work, the main value types in Grace, the main literals — Strings, Numbers — must be patterns that match themselves. That's what lets things like this work:

```
method fib(n : Number) {
  match (n)
    case { 0 −> 0 }
    case { 1 −> 1 }
    case { _ −> fib(n−1) + fib(n−2) }
}
```

With this design, there is a potential ambiguity regarding Booleans: "true || false" as an expression is very different from "true | false" as a composite pattern! Unfortunately, if Booleans are Patterns, then there's no way the type checker can distinguish these two cases.

If you want to match against objects that are not patterns, you can lift any object to a pattern that matches just that object by writing e.g. LiteralPattern.new(o) (option — or something shorter, like a prefix =~?).

9.3 Exceptions (under discussion)

Grace supports exceptions, which can be raised and caught. Exceptions are raised by requesting the raise method from an Exception object, with a string argument explaining the problem.

```
    userException.raise "Oops...!"
```

Exceptions are caught by a catch(1)case(1)...case(1) construct that syntactically parallels match(1)case(1)". **Andrew** ▶*This is a bad name.* try{} catch{} catch{} *would make more sense.*◀

```
catch {def f = File.open("data.store")}
    case {e : NoSuchFile −> print("No Such File"); return}
    case {e : PermissionError −> print("Permission denied"); return}
```

```
    case {Exception −> print("Unidentified Error); System.exit}
    finally {f.close}
```

Raising an Exception terminates the execution of the expression containing the raise request; it is not possible to restart or resume that execution[1].

Andrew ▶*continue here*◀

"catch(1)case(1)finally(1)" construct and a "do(1)finally(1)" construct support finalization even through exceptions. Following Scala, a "using(1)do(1)" construct supports resource allocation and deallocation:

```
using (Closable.new) do { stranger −> // bound to the new Closable
    stranger.doSomething
}
// the close method is automatically requested of the
// Closable when the block terminates
```

10 Equality and Value Objects

All objects automatically implement the following non-overridable methods. (option) Library programmers are able to override these methods.

1. == and != operators implemented as per Henry Baker's "egal" predicate [2]. That is, immutable objects are egal if they are of the same "shape", have the same methods declared in the same lexical enviornments, and if their fields' contents are egal, while mutable objects are only ever egal to themselves.

2. hashcode compatible with the egal.

As a consequence, immutable objects (objects with no **var** fields, which capture only other immutable objects) act as pure "value objects" without identity. This means that a Grace implementation can support value objects using whatever implementation is most efficient: either passing by reference always, by passing some times by value, or even by inlining fields into their containing objects, and updating the field if the containing object assigns a new value.

[1] However, implementors should pickle the stack frames that are terminated when an exception is raised, so that they can be used in the error reporting machinery (debugger, stack trace)

11 Types

Grace uses structural typing [11, 34, 17]. Types primarily describe the requests objects can answer. Fields do not directly influence types, except in so far as a field with publicly-visible accessor methods cause those methods to be part of the type (and in general to be visible to unconstrained clients).

Unlike in other parts of Grace, Type declarations are always statically typed, and their semantics may depend on the static types. The main case for this is determining between identifiers that refer to types, and those that refer to constant name definitions (introduced by **def**) which are interpreted as Singleton types.

11.1 Basic Types

Grace's standard prelude defines the following basic types: **Kim** ▶*We should specify the signature of each of these types. I've listed some here, but it would be better to just write out the full type definitions.*◀

- Nothing — an uninhabited type. Nothing conforms to all other types. **Kim** ▶*Perhaps we should consider undefined as a member.*◀ **Andrew** ▶*Since one can nerver dereference an in defined variable, one can never request a method from undefined.*◀

- Done — the type of the object returned by assignments and methods that have nothing interesting to return. **Andrew** ▶*All other types conform to Done?*◀ The only method on such objects is asDebugString **Kim** ▶*Minigrace includes == and !=. That seems reasonable to me.*◀

- Object — the common interface of most objects. Object can also be written {}. **Kim** ▶*It has methods ==, !=, and asString. We should specify that these are part of all types. How do we distinguish between Done and Object structurally?*◀

- Boolean — methods for true and false **Kim** ▶*Has operations/methods ++ (string concatenation), &&, ||, ==, ! =, ! (prefix-not), not, ifType, asString, and match.*◀

- Number — numbers **Kim** ▶*Has operations/methods +, ∗, −, /, %, ^, ==, ! =, / =, ++, <, <=, >, >=, .., asString, − (prefix), inBase, truncate, and match.*◀

- String — strings, and individual characters **Kim** ▶*Has operations ++, size, ord, at, [], ==, ! =, / =, iter, substringFrom()to, replace()with, hash code, indices, asString, asNumber, match*◀
- Pattern — pattern used in match/case statements

In addition, variables can be annotated as being Dynamic. Dynamic is not a type, but a label that the type system uses when reasoning about the values of expressions. Dynamic is also implicitly assigned to parameters and variables for which no type is declared.

11.2 Types

Types define the interface of objects by detailing their public methods, and the types of the arguments and results of those methods. Types can also contain definitions of other types.

The various Cat object and class descriptions (see §7) would produce objects that conform to an object type such as the following. Notice that the public methods implicitly inherited from Object are implicitly included in all types.

```
{
        colour -> Colour
        name -> String
        miceEaten -> Number
        miceEaten:= (_ : Number) -> Done
}
```

For commonality with method declarations, method arguments are normally named in type declarations. These names are useful when writing specifications of the methods. If a parameter name is omitted, it must be replaced by an underscore. The type of a parameter may be omitted, in which case the type is Dynamic.

11.3 Type Declarations

Types — and generic types — may be named in type declarations:

```
type MyCatType = { color -> Colour; name -> String }
    // I care only about names and colours

type MyGenericType<A,B> =
    where A <: Hashable, B <: DisposableReference
```

```
{
    at (_:A) put (_:B) -> Boolean
    cleanup(_:B)
}
```

Grace has a single namespace: types live in the same namespace as methods and variables.

Kim ▶*There is no advantage to writing constraints on the type parameters in generic type definitions. Those really only make sense for classes and methods. In particular, you can't write a type definition that only makes sense when constrained.*◀

James ▶*Declaring generic types with = like this is very confusing! How do we write an anonymous, structural, generic type? Do we need to? Or aren't we able to write such types?*◀

Kim ▶*I suppose we could instead write:*◀

```
type MyGenericType = <A,B>
{
    at (_:A) put (_:B) -> Boolean
    cleanup(_:B)
}
```

Kim ▶*We still do have a problem inserting type definitions in a context. How can we distinguish it from a block? Perhaps we need to say that only type names (possibly with a prefix path and type parameters after) can appear in a context expecting a type expression.*◀

11.4 Relationships between Types — Conformance Rules

The key relation between types is **conformance**. We write B <: A to mean B conforms to A; that is, that B is a subtype of A, A is a supertype of B. This section draws heavily on the wording of the Modula-3 report [11], with apologies to Luca Cardelli et al.

If B <: A, then every object of type B is also an object of type A. The converse does not apply.

If A and B are ground object types, then B <: A iff for every method m in A, there is a corresponding method m (with the same name) in B such that

- The method m in B must have the same number of arguments as m in A, with the same distribution in multi-part method names.
- If the method m in A has signature "$(P_1, ...P_n)$ -> R" and m in B has signature "$(Q_1, ...Q_n)$ -> S" then

- Argument types must be contravariant: $P_i <: Q_i$
- Results types must be covariant: S <: R

Kim ▶*I almost feel the signature should be further subdivided to reflect multi-part names, but that seems too painful.*◀

If a class or object B inherits from another class A, then B's type should conform to A's type. If A and B are generic classes, then similar instantions of their types should conform. **Kim** ▶*Need to reword and resolve what this means. Could allow, but make type checker work harder – all the way up the inheritance chain or disallow. This does not make it clear.*◀

The conformance relationship is used in **where** clauses to constrain formal generic type parameters of classes and methods. **Kim** ▶*Not really – must define matches*◀

11.5 Variant Types

Variables with untagged, retained variant types, written T1 | T2 ... | Tn , may refer to an object of any one of their component types. No *objects* actually have variant types, only expressions. The actual type of an object referred to by a variant variable can be determined using that object's reified type information. **Andrew** ▶*I reworded the above. Is it what we mean?*◀

The only methods that may be requested via a variant type are methods with exactly the same declaration across all members of the variant. (Option) methods with different signatures may be requested at the most most specific argument types and least specific return type. **Kim** ▶*If we choose this, we should write it more carefully.*◀

Variant types are retained as variants: they are *not* equivalent to the object type which describes all common methods. This is so that the exhaustiveness of match/case statements can be determined statically. Thus the rules for conformance are more restrictive:

S <: S | T; T <: S | T
(S' <: S) & (T' <: T) ==⇒ (S' | T') <: (S | T)

Kim ▶*Added this example. Does it help?*◀ The following example illustrates the limitations. Suppose

type S = {m: A −> B, n:C −> D}
type T = {m: A −> B, k: E −> F}
type U = {m: A −> B}

Then U fails to conform to S | T even though U contains all methods continued in both S and T. **Kim** ▶*fix font of S,T,U*◀

11.6 Intersection Types

(option) An object conforms to an Intersection type, written T1 & T2 & ... & Tn, if and only if that object conforms to all of the component types. The main use of intersection types is as bounds on **where** clauses.

```
class Happy<T>
    where T <: (Comparable<T> & Printable & Happyable)
{  p ->
                    ...
}
```

11.7 Union Types

(option) Structural union types (sums), written T1 + T2 + ... + Tn, may refer to an object that conforms to any of the component types. Unions are mostly included for completeness: variant types subsume most uses.

11.8 Type subtraction

(option) A type written T1 − T2 has the interface of T1 without any of the methods in T2. **Kim** ▶*Need to tighten up this definition.*◀

11.9 Singleton Types

James ▶*How does this work with the "new" pattern matching interpretation? I think singleton objects must be self-matching for this to work reliably*◀

The names of singleton objects, typically declared in object declarations, may be used as types. Singleton types match only their singleton object. Singleton typs can be distinguised from regular types because Grace type declarations are statically typed.

```
def null = object { method isNull -> Boolean {return true} }

type Some<T> { thing -> T
                    method isNull -> Boolean }

type Option<T> = Some<T> | null
```

Kim ▶*Fixed type of thing above. Correct? Also changed from class to type as can't use classes as types.*◀

11.10 Nested Types

Type definitions may be nested inside other expressions, for example, they may be defined inside object, class, method, and other type definitions. If they are defined inside object, class, and other type definitions they are accessed using "dot" notation,, written o.T,

In this way a type may be used as a specification module. Types may also be imported from modules, since modules are objects.

11.11 Additional Types of Types

(Option) Grace may support exact types (written =Type)

(option) Grace probably will probably not support Tuple types, probably written Tuple<T1, T2, ..., Tn>.

(Option) Grace may support selftypes, written **Selftype**.

11.12 Syntax for Types

This is very basic - but hopefully better than nothing!

```
Type := GroundType | (Type ("|" | "&") Type) | "(" Type ")"
GroundType ::= BasicType | BasicType "<" Type ","... ">" | "Selftype"
BasicType ::= TypeID | "=" TypeID
```

11.13 Reified Type Information Metaobjects and Type Literals

(option) Types are represented by objects of type Type (Hmm, should be Type<T>?). Since Grace has a single namespace, so types can be accessed by requesting their names.

To support anonymous type literals, types may be written in expressions: **type** Type. This expression returns the type metaobject representing the literal type.

Kim ▶*I don't understand the need for this. Can someone give an example?*◀

11.14 Type Assertions

(option) Type assertions can be used to check conformance and equality of types.

```
assert {B <: A}
    // B 'conforms to' A.
```

```
assert {B <: {foo(_:C) -> D} }
   // B had better have a foo method from C returning D
assert {B = A | C}
```

11.15 Notes

1. (**Sanity Check**) these rules Kim ►*????*◄
2. What's the relationship between "type members" across inheritance (and subtyping???) Kim ►*No variance in type definitions when inherit.*◄
3. On matching, How does destructuring match works? What's the protocol? Who defines the extractor method? (not sure why this is here) Kim ►*Doesn't this go back in matching section?*◄
4. can a type extend another type? Kim ►*Yes, though we use & to denote it.*◄ Kim ►*May be an issue – and distinction – if we allow SelfType*◄
5. Structural typing means we neither need nor want any variance annotations! Because Grace is structural, programmers can always write an (anonymous) structural type that gives just the interface they need — or such types could be stored in a library. Kim ►*Yes. Move this somewhere reasonable in the spec.*◄
6. ObjectTypes require formal parameter names & need to fix examples. §11.2?
7. Tuples §11.11. Syntax as a type? Literal Tuple Syntax?
8. Nesting.
9. Serialization
10. Include dialect description.

12 Pragmatics

The distribution medium for Grace programs, objects, and libraries is Grace source code.

Grace source files should have the file extension .grace. If, for any bizzare reason a trigraph extension is required, it should be .grc

Grace files may start with one or more lines beginning with "#": these lines are ignored.

12.1 Garbage Collection

Grace implementations should be garbage collected. Safepoints where GC may occur are at any backwards branch and at any method request.

Grace will not support finalisation. Kim ►*Seems like we will need it!*◄

12.2 Concurrency and Memory Model

The core Grace specification does not describe a concurrent language. Different concurrency models may be provided as dialects.

Grace does not provide overall sequential consistency. Rather, Grace provides sequential consistency within a single thread. Across threads, any value that is read has been written by some thread sometime — but Grace does not provide any stronger guarantee for concurrent operations that interfere. Kim ►*Semantics of language must be independent of the hardware specs.*◄

Grace's memory model should support efficient execution on architectures with Total Store Ordering (TSO).

13 Libraries

Kim ►*Need to put standard libraries in appendices.*◄

13.1 Collections

Grace will support some collection classes.

Collections will be indexed 1..size by default; bounds should be able to be chosen when explicitly instantiating collection classes.

Acknowledgements

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Thanks to Michael Homer and Ewan Tempero for their comments on drafts.

The Scala language specification 2.8 [39] and the Newspeak language specification 0.05 [6] were used as references for early versions of this document. The design of Grace (so far!) has been influenced by Algol [41, 38], AmbientTalk [12], AspectJ [29], BCPL [42], Beta [33], Blue [30, 31, 32], C [28], C++ [44], C♯ [4, 3], Dylan [43], Eiffel [35, 36], Emerald [5], F_1 [10],

$F\sharp$ [46], *FGJ* [24], $FJ\vee$ [25], FORTRESS [1], gBeta [14], Haskell [22], Java [13, 18], Kevo [47], Lua [23], Lisp [16], ML [37], Modula-2 [51], Modula-3 [11], Modular Smalltalk [50], Newspeak [8, 6], Pascal [27], Perl [49], Racket [15], Scala [40, 39], Scheme [45], Self [48], Smalltalk [19, 26, 9, 7], Object-Oriented Turing [21], Noney [34], and Whiteoak [17] at least: we apologise if we've missed any languages out. All the good ideas come from these languages: the bad ideas are all our fault [20].

A To Be Done

As well as the large list in Section 1 of features we haven't started to design, this section lists details of the language that remain to be done:

1. specify full numeric types **Kim** ►*Should be single type not types*◄

2. Block::apply §5 — How should we spell "apply"? "run"? **Kim** ►*decided on apply*◄ **Andrew** ►*Because mapping can be represented by Maps and Functions, thee is an argument to spell "apply" and "at" he same way. "at" is also shorter than "apply".*◄

3. confirm method lookup algorithm, in particular relation between lexical scope and inheritance (see §8) ("Out then Up"). Is that enough? Does the no-shadowing rule work? If it does, is this a problem? **Kim** ►*We seem to have given up on the no-shadowing rule. The general rule for name lookup is that all paths are explored. If two paths give same name then the using occurrence must be annotated with self or some number of outers to disambiguate the use.*◄ **Andrew** ►*I can't see any reason to allow method or block temporaries and parameters to shadow variables from an enclosing lexical scope. But method names are different: programmers are not free to choose their own method names, because they may have to implement a type. Minigrace currently implements outer dynamically, as a method that resolves to the enclosing* object. *So I think that there is no way to explicitly refer to a shadowed name in an enclosing method.*◄

4. confirm "super" or other mechanism for requesting overridden methods §8.6. **Kim** ►*We seem to have settled on super.*◄

5. confirm "outer" as meaning "the object enclosing self" **Kim** ►*Current decision*◄ §8.7

   Kim ►*My e-mail to grace-core raises issues with understanding "outer". Currently it is the "self" for the object enclosing the current "self"*◄

6. update grammar to incude "outer" §8.7.

7. confirm rules on named method argument parenthesization §8.1

8. how are (mutually) recursive names initialised?

9. make the **def** keyword optional, or remove it, or return to **const** §6.1 **Kim** ►*No! leave it as it is.*◄

10. support multiple constructors for classes §7.2 **Kim** ▶*Show how it is done, but no need for separate syntax.*◀

11. where should we draw the lines between object constructor expressions/named object declarations, class declarations, and "hand-built" classes? §7.3 **Kim** ▶*Don't understand what the issue is.*◀

12. what's the difference between **class** FOO {} and **def** FOO = **class** {} (for various values of "class") **Kim** ▶*The second is not currently legal, though could write def of factory object generating similar items as class.* ◀

13. how do factories etc relate to "uninitialized" §6.2

14. decide what to do about equality operators §10 **Kim** ▶*Thiat is important!*◀

15. Support for identifying static type decltype and dynamic type typeid/foo.getType

16. Support for type test (like instanceof) and static casts. More to the point, what is the type system? **Kim** ▶*We should insert definition. We don't support instance of, instead use match*◀

17. Multiple Assignment §6.2 **Kim** ▶*Why bother?*◀

18. Type assertions — should they just be normal assertions between types? so *e.g.*, <: could be a normal operator between types.

19. Grace needs subclass compatibility rules **Kim** ▶*YES!!*◀

20. BRANDS. Brand Brand Brand. **Kim** ▶*Maybe not needed*◀

21. weak references **Kim** ▶*???? why?*◀

B Grammar

```
// top level
def program = rule {codeSequence ~ rep(ws) ~ end}
def codeSequence = rule { repdel((declaration | statement), semicolon) }
def innerCodeSequence = rule { repdel((innerDeclaration | statement), semicolon) }


// declarations

def declaration = rule { varDeclaration | defDeclaration | classDeclaration |
                         typeDeclaration | methodDeclaration }
def innerDeclaration = rule { varDeclaration | defDeclaration | classDeclaration |
```

```
                                    typeDeclaration }

  def varDeclaration = rule { varId ~ identifier ~ opt(colon ~ typeExpression) ~
                                  opt(assign ~ expression) }
  def defDeclaration = rule { defId ~ identifier ~ opt(colon ~ typeExpression) ~
                                  equals ~ expression }
  def methodDeclaration = rule { methodId ~ methodHeader ~ methodReturnType ~ whereClause ~
                                    lBrace ~ innerCodeSequence ~ rBrace }
  def classDeclaration = rule { classId ~ identifier ~ dot ~ classHeader ~ methodReturnType ~ whereClause ~
                                    lBrace ~ inheritsClause ~ codeSequence ~ rBrace }

  //def oldClassDeclaration = rule { classId ~ identifier ~ lBrace ~
  // opt(genericFormals ~ blockFormals ~ arrow) ~ codeSequence ~ rBrace }


  //warning: order here is significant!
  def methodHeader = rule { accessingAssignmentMethodHeader | accessingMethodHeader |
                                    assignmentMethodHeader |
                                    methodWithArgsHeader | unaryMethodHeader | operatorMethodHeader |
                                    prefixMethodHeader }

  def classHeader = rule { methodWithArgsHeader | unaryMethodHeader }
  def inheritsClause = rule { opt( inheritsId ~ expression ~ semicolon ) }

  def unaryMethodHeader = rule { identifier ~ genericFormals }
  def methodWithArgsHeader = rule { firstArgumentHeader ~ repsep(argumentHeader,opt(ws)) }
  def firstArgumentHeader = rule { identifier ~ genericFormals ~ methodFormals }
  def argumentHeader = rule { identifier ~ methodFormals }
  def operatorMethodHeader = rule { otherOp ~ oneMethodFormal }
  def prefixMethodHeader = rule { opt(ws) ~ token("prefix") ~ otherOp } // forbid space after prefix?
  def assignmentMethodHeader = rule { identifier ~ assign ~ oneMethodFormal }
  def accessingMethodHeader = rule { lrBrack ~ genericFormals ~ methodFormals }
  def accessingAssignmentMethodHeader = rule { lrBrack ~ assign ~ genericFormals ~ methodFormals }

  def methodReturnType = rule { opt(arrow ~ nonEmptyTypeExpression ) }

  def methodFormals = rule { lParen ~ rep1sep( identifier ~ opt(colon ~ typeExpression), comma) ~ rParen}
  def oneMethodFormal = rule { lParen ~ identifier ~ opt(colon ~ typeExpression) ~ rParen}
  def blockFormals = rule { repsep( identifier ~ opt(colon ~ typeExpression), comma) }

  def matchBinding = rule{ (identifier | literal | parenExpression) ~
                                  opt(colon ~ nonEmptyTypeExpression ~ opt(matchingBlockTail)) }
  def matchingBlockTail = rule { lParen ~ rep1sep(matchBinding, comma) ~ rParen }

  def typeDeclaration = rule { typeId ~ identifier ~ genericFormals ~
                                    equals ~ nonEmptyTypeExpression ~ semicolon ~ whereClause}

  def typeExpression = rule { (opt(ws) ~ typeOpExpression ~ opt(ws)) | opt(ws) }
  def nonEmptyTypeExpression = rule { opt(ws) ~ typeOpExpression ~ opt(ws) }

  def typeOp = rule { opsymbol("|") | opsymbol("&") | opsymbol("+") }

  // def typeOpExpression = rule { rep1sep(basicTypeExpression, typeOp) }

  def typeOpExpression = rule { // this complex rule ensures two different typeOps have no precedence
    var otherOperator
```

```
  basicTypeExpression ~ opt(ws) ~
    opt( guard(typeOp, { s -> otherOperator:= s; true }) ~
         rep1sep(basicTypeExpression ~ opt(ws),
             guard(typeOp, { s -> s == otherOperator })
         )
    )
  }

def basicTypeExpression = rule { nakedTypeLiteral | literal | pathTypeExpression | parenTypeExpression }
    // if we keep this, note that in a typeExpression context { a; } is interpreted as type { a; }
    // otherwise as the block { a; }

def pathTypeExpression = rule { opt(superId ~ dot) ~ rep1sep((identifier ~ genericActuals),dot) }

def parenTypeExpression = rule { lParen ~ typeExpression ~ rParen }



// statements

def statement = rule { returnStatement | (expression ~ opt(assignmentTail)) }
     // do we need constraints here on which expressions can have an assignmentTail
     // could try to rewrite as options including (expression ~ arrayAccess ~ assignmentTail)
     // expression ~ dot ~ identifier ~ assignmentTail

def returnStatement = rule { symbol("return") ~ opt(ws) ~ opt(expression) } //doesn't need parens
def assignmentTail = rule { assign ~ expression }

// expressions

def expression = rule { opExpression }

//def opExpression = rule { rep1sep(addExpression, otherOp)}

def opExpression = rule { // this complex rule ensures two different otherOps have no precedence
  var otherOperator
  addExpression ~ opt(ws) ~
    opt( guard(otherOp, { s -> otherOperator:= s; true }) ~
         rep1sep(addExpression ~ opt(ws),
             guard(otherOp, { s -> s == otherOperator })
         )
    )
  }

def addExpression = rule { rep1sep(multExpression, addOp) }
def multExpression = rule { rep1sep(prefixExpression, multOp) }
def prefixExpression = rule { (rep(otherOp) ~ selectorExpression) | (rep1(otherOp) ~ superId) }
       // we can have !super

def selectorExpression = rule { primaryExpression ~ rep(selector) }

def selector = rule { (dot ~ unaryRequest) |
                      (dot ~ requestWithArgs) |
                      (lBrack ~ rep1sep(expression,comma) ~ rBrack)
                    }
```

```
def operatorChar = CharacterSetParser.new("!?@#$%^&|~=+-*/><:.") // had to be moved up

//special symbol for operators: cannot be followed by another operatorChar
method opsymbol(s : String) {trim(token(s) ~ not(operatorChar))}

def multOp = opsymbol "*" | opsymbol "/"
def addOp = opsymbol "+" | opsymbol "-"
def otherOp = rule { guard(trim(rep1(operatorChar)), { s -> ! parse(s) with( reservedOp ~ end ) })}
    // encompasses multOp and addOp
def operator = rule { otherOp | reservedOp }

def unaryRequest = rule { trim(identifier) ~ genericActuals ~ not(delimitedArgument) }
def requestWithArgs = rule { firstRequestArgumentClause ~ repsep(requestArgumentClause,opt(ws)) }
def firstRequestArgumentClause = rule { identifier ~ genericActuals ~ opt(ws) ~ delimitedArgument }
def requestArgumentClause = rule { identifier ~ opt(ws) ~ delimitedArgument }
def delimitedArgument = rule { argumentsInParens | blockLiteral | stringLiteral }
def argumentsInParens = rule { lParen ~ rep1sep(drop(opt(ws)) ~ expression, comma) ~ rParen
}

def implicitSelfRequest = rule { requestWithArgs | rep1sep(unaryRequest,dot) }

def primaryExpression = rule { literal | nonNakedSuper | implicitSelfRequest | parenExpression }

def parenExpression = rule { lParen ~ rep1sep(drop(opt(ws)) ~ expression, semicolon) ~ rParen }
                                    // TODO should parenExpression be around a codeSequence?

def nonNakedSuper = rule { superId ~ not(not( operator|lBrack )) }

// "generics"
def genericActuals = rule { opt(lGeneric ~ opt(ws) ~
                            rep1sep(opt(ws) ~ typeExpression ~ opt(ws),opt(ws) ~ comma ~ opt(ws)) ~
                            opt(ws) ~ rGeneric) }

def genericFormals = rule { opt(lGeneric ~ rep1sep(identifier, comma) ~ rGeneric) }

def whereClause = rule { repdel(whereId ~ typePredicate, semicolon) }
def typePredicate = rule { expression }

//wherever genericFormals appear, there should be a whereClause nearby.


// "literals"

def literal = rule { stringLiteral | selfLiteral | blockLiteral | numberLiteral |
                     objectLiteral | tupleLiteral | typeLiteral }

def stringLiteral = rule { opt(ws) ~ doubleQuote ~ rep( stringChar ) ~ doubleQuote ~ opt(ws) }
def stringChar = rule { (drop(backslash) ~ escapeChar) | anyChar | space}
def blockLiteral = rule { lBrace ~ opt( (matchBinding | blockFormals) ~ arrow)
                                  ~ innerCodeSequence ~ rBrace }
def selfLiteral = symbol "self"
def numberLiteral = trim(DigitStringParser.new)
def objectLiteral = rule { objectId ~ lBrace ~ inheritsClause ~ codeSequence ~ rBrace }
def tupleLiteral = rule { lBrack ~ repsep( expression, comma ) ~ rBrack }

def typeLiteral = rule { typeId ~ opt(ws) ~ nakedTypeLiteral }
```

```
def nakedTypeLiteral = rule { lBrace ~ opt(ws) ~
                              repdel(methodHeader ~ methodReturnType, (semicolon | whereClause)) ~
                              opt(ws) ~ rBrace }

// terminals
def backslash = token "\\" // doesn't belong here, doesn't work if left below!
def doubleQuote = token "\""
def space = token " "
def semicolon = rule { (symbol(";") ~ opt(trim(newLine))) }
def colon = rule {both(symbol ":",not(assign))}
def newLine = symbol "\n"
def lParen = symbol "("
def rParen = symbol ")"
def lBrace = symbol "\{"
def rBrace = symbol "\}"
def lBrack = symbol "["
def rBrack = symbol "]"
def lrBrack = symbol "[]"
def arrow = symbol "->"
def dot = symbol "."
def assign = symbol ":="
def equals = symbol "="

def lGeneric = token "<"
def rGeneric = token ">"

def comma = rule { symbol(",") }
def escapeChar = CharacterSetParser.new("\\\"'\{\}bnrtlfe ")

def azChars = "abcdefghijklmnopqrstuvwxyz"
def AZChars = "ABCDEFGHIJKLMNOPQRSTUVWXYZ"
def otherChars = "1234567890~!@#$%^&*()_-+=[]|\:;<,>.?/"

def anyChar = CharacterSetParser.new(azChars ++ AZChars ++ otherChars)

def identifierString = trim(GraceIdentifierParser.new)

// def identifier = rule { bothAll(trim(identifierString),not(reservedIdentifier)) }
                            // bothAll ensures parses take the same length
// def identifier = rule{ both(identifierString,not(reservedIdentifier)) }
                            // both doesn't ensure parses take the same length
def identifier = rule { guard(identifierString, { s -> ! parse(s) with( reservedIdentifier ~ end ) })}
                          // probably works but runs out of stack

// anything in this list needs to be in reservedIdentifier below (or it won't do what you want)
def superId = symbol "super"
def extendsId = symbol "extends"
def inheritsId = symbol "inherits"
def classId = symbol "class"
def objectId = symbol "object"
def typeId = symbol "type"
def whereId = symbol "where"
def defId = symbol "def"
def varId = symbol "var"
def methodId = symbol "method"
def prefixId = symbol "prefix"
```

```
def interfaceId = symbol "interface"

def reservedIdentifier = rule {selfLiteral | superId | extendsId | inheritsId |
            classId | objectId | typeId | whereId |
            defId | varId | methodId | prefixId | interfaceId } // more to come

def reservedOp = rule {assign | equals | dot | arrow | colon | semicolon} // this is not quite right
```

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